

**Annual Technical Report: Award 02HQGR0104**

**SOURCE PARAMETER STUDIES OF HISTORICAL (1930-1964)  
INTRASLAB AND CRUSTAL EARTHQUAKES OF WASHINGTON  
AND OREGON: COLLABORATIVE RESEARCH WITH THE  
UNIVERSITY OF TEXAS AT EL PASO, AND BOISE STATE  
UNIVERSITY**

**Period 06/01/02 – 05/31/03**

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Crustal Earthquakes of Washington and Oregon: Collaborative  
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**Abstract**

Historical seismograms from a number of Puget Sound area earthquakes, 1932-1964, have been examined and copied at archives at Seattle and Berkeley. This process has uncovered a number of inconsistencies in earlier catalogs, particularly in relative magnitude of events. At the same time, however, it has shown the historical seismograms studied to date to contain a wealth of previously unutilized information useful in determining events' locations and source mechanisms. Use of inexpensive flatbed scanners and image enhancement programs allow details previously either dimly glimpsed or unsuspected to be seen on many seismograms.

While work is still in progress, some of the more significant preliminary results include (1) an indication that multiple subevents occurred in the first 1-2 seconds of the 1965 M6.5 Seattle earthquake, (2) suggestions that earthquake magnitudes for early 1960s events may be underestimated, and (3) reducing the magnitude of a 1953 Portland area event from magnitude 5 to closer to 4. Source mechanism studies are underway at UTEP.

## Introduction

We are examining and modeling regional and teleseismic seismograms for historic intraslab and crustal events (1932-1968) of  $M \sim 5+$  occurring within the Pacific Northwest (Washington and Oregon) region to better determine the source locations, source mechanisms and rupture histories. A better understanding of the depth range and rupture extent of intraslab events will aid other researchers in determining the physical processes (e.g. dehydration, phase changes) that control slab rupture. The results will provide insight into why there is such a strong concentration of large intraslab events on the southern side of the “bulge” in the subducting slab. We are also examining crustal events ( $M4.5+$ ) within the forearc and backarc of the Cascadia region. Although moderate to large crustal events in Cascadia have not been as numerous as intraslab events over the past century, study of the crustal events that have occurred will help in assessing seismic hazard associated with these shallow events. Also, the nature (intraslab or forearc/backarc crustal) of many of the events prior to about 1970 appears to have been misidentified in available catalogs, mostly as the result of sparse seismograph station distribution and lack of comparison with better recorded events.

Events we are concentrating upon in this project are listed in Tables 1 and 2. The events in Table 2, which are better instrumented than older events, serve as comparison/calibration events.

Source parameters of historic earthquakes, including locations, focal depths, focal mechanisms, and rupture histories, are being determined through use of local, regional and teleseismic waveform data. Sufficient seismograms are available for the largest (generally  $M \geq 5.8$ ) events to invert regional and/or teleseismic data for source parameter information. For moderate sized events we hope to narrow the range of possible focal mechanisms and focal depths, even if sufficient data are not available for a complete, detailed waveform inversion. Aiding us in the analysis process is the wealth of digital waveform data available from recent (post-1989) moderate and large earthquakes occurring within the same areas as the historic events. This allows direct waveform comparisons between recent and historic events and may provide empirical Greens functions that can be used in deconvolution routines to determine the rupture processes of the historic events.

A necessary part of the work has been the examination of historical seismograms from local, regional, and teleseismic stations. Instead of simply being copied, the records are being scanned with inexpensive flatbed scanners. The scanned images have shown a surprising amount of detail, which will be useful not only for source mechanism studies but also in better determination of hypocenters and magnitudes of the events studied.

It is extremely difficult to obtain multiple seismograms for a single event for moderate sized earthquakes occurring in this region prior to 1932. Local stations began recording in 1899 (Victoria, B. C.), 1906 (Seattle), and 1910 (Spokane), but most seismograms for Victoria and Seattle prior to 1928 have been lost. Important archives of Spokane seismograms have been located in this study and found to be of mainly good quality. A preliminary examination of Seattle and Berkeley seismogram archives has been made.

**Table 1. Historical Events Being Studied**

<u>Date</u>	<u>Time</u>	<u>Lat</u>	<u>Long</u>	<u>M</u>	<u>Name*</u>
071732	1002	47.6	-121.8	5	[CF] Tolt River
071636	0707	45.97	-118.21	5.8 M <sub>S</sub>	[CB] Milton-Freewater
111339	0745	47.5	-122.5	5.8 M <sub>S</sub>	[I] S. Puget Sound
042945	2016	47.4	-121.7	5.5 M <sub>S</sub>	[CF] North Bend
021546	0317	47.4	-122.7	5.8 M <sub>S</sub>	[I]? Puget Sound
041349	1955	47.17	-122.62	6.7 M <sub>w</sub>	[I] Olympia
121653	0432	45.50	-122.7	4 M <sub>L</sub>	[CF] Portland
051554	1302	48.0	-122.0	5.0 M <sub>L</sub>	[CF]? Snohomish
012657	0116	48.33	-122.32	5.0 M <sub>L</sub>	[CF]? Mt. Vernon
080659	0344			5.0 M <sub>L</sub>	[CB] Lake Chelan
091761	1555	46.02	-122.12	5.1 M <sub>L</sub>	[CF] Siouxi Peak
110761	2130	45.7	-122.9	3.9 M <sub>L</sub>	[CF] Portland
123162	2049	47.1	-122.0	4.7 M <sub>D</sub>	[CF]? Orting
030763	2353	44.9	-123.7	5 M <sub>L</sub>	[I] Lincoln City
071464	1550	48.9	-122.5	5 M <sub>L</sub>	[CF]? Bellingham

**Table 2. Comparison and Calibration Events**

<u>Date</u>	<u>Time</u>	<u>Lat</u>	<u>Long</u>	<u>M<sub>w</sub></u>	<u>Name*</u>
110662	0336	45.64	-122.59	5.2 M <sub>L</sub>	[C] Portland
042965	1528	47.4	-122.3	6.5 M <sub>S</sub>	[I] South Seattle
060368	1327	42.3	-119.8	5.0 m <sub>b</sub>	[C] Warner Valley
021481	0609	46.35	-122.23	5.5 M <sub>L</sub>	[C] Elk Lake
052881	0910	46.53	-121.39	5.0 M <sub>L</sub>	[CF] Goat Rocks
122489	0845	46.65	-122.12	5.1 M <sub>L</sub>	[C] Storm King Mtn
041490	0533	48.85	-122.16	5.2 M <sub>L</sub>	[C] Deming
032593	1334	45.17	-122.07	5.6 M <sub>w</sub>	[C] Scotts Mills
092193	0328	42.31	-122.01	6.0 M <sub>w</sub>	[C] Klamath Falls
012995	0311	47.39	-122.36	5.1 m <sub>b</sub>	[C] Robinson Pt.
050396	0404	47.76	-121.88	5.5 M <sub>L</sub>	[C] Duval
062397	1913	47.60	-122.57	5.0 m <sub>b</sub>	[C] Bremerton
070399	0143	47.08	-123.46	5.8 M <sub>w</sub>	[I] Satsop
022801	1854	47.14	-122.72	6.8 M <sub>w</sub>	[I] Nisqually

\*I= intraslab, C= crustal, F= forearc, B= backarc

### **Description of Seismogram Archives Examined to Date**

A large archive of seismogram copies of Puget Sound events collected several years ago by the PI was located and transferred to UTEP. This very large collection consisted of over 150 seismogram copies from mainly regional and teleseismic distances. A few original Spokane records were included in the collection. They had been misfiled (and never returned) after being borrowed by another institution more than 50 years ago. They will be sent to the University of Washington library at the completion of this study.

Seismogram archives for Seattle (SEA) and Spokane (SPO) contained at the University of Washington library were examined, as was the seismogram archive at Berkeley. The SEA archive has been largely untouched by modern researchers, particularly for the pre-1949 period. The SPO archive has probably never been examined in detail by other researchers.

The SEA archive consists of SEA seismograms from about 1928 through 1957, seismograms for three stations (SEA, Tumwater – TUM, and Longmire – LON) from 1957 to about 1970, and later SEA and LON seismograms. Beginning in 1969, a regional telemetry network was installed and gradually the paper seismograms from these stations were deemed less important. Although SEA still records paper seismograms as a display, the paper seismograms for LON were terminated about 1988. LON was a WWNSS station beginning about 1962 and a DWWSS beginning in 1980, so data from this station using different instruments is available for much later events. SEA began as a 2-horizontal-component (Bosch-Omori) station and operated that way until about 1950. Beginning in 1950, a variety of electromagnetic seismographs were operated at SEA. The Bosch-Omori (B-O) records are smoked paper and have a gain of 35.

SPO began operating a 2-component Wiechert seismograph, recording on smoked paper, in 1910. The gain was 80. At some point in the 1950s, electromagnetic seismographs were introduced. The Wiechert continued to operate at least until 1957, providing an exceptionally stable basis of comparison for many events. The electromagnetic seismograph records examined to date have been rather disappointing in terms of record-keeping and gain. In the late 1960s a 3-component short period Benioff station was installed, but only operated until about 1970 when the station was permanently closed. Its records appear to have been of fairly low gain and may not be useful to this study.

The PI had made a preliminary examination of a few SEA records a number of years ago, and was familiar with Wiechert records from other studies. However, the quality of many of the SEA and SPO records examined was surprisingly good. While we are concentrating in this project on moderate to large events which overload local seismographs' recording capabilities, it was found that P waves were often sharp and S waves could be seen and timed in some cases. Regrettably, little clock correction information seems to be available for SEA prior to 1950, or for SPO (clock corrections are sometimes written on the records). However, polarity information can usually be obtained from the seismograms. In general, the information available from these records is very much better than was expected.

The Berkeley archive (for the University of California Seismograph Stations, or UCSS) contains seismograms going back as far as 1910. The Berkeley network has a complicated station and instrumentation history, and will not be discussed in detail here. Of great importance for comparative purposes is the operation (at BRK) of a set of Galitzin seismographs from about 1930 to 1960, and a Benioff short-period vertical beginning about 1932. A sensitive station at Mineral (MIN) in northern California was equipped with a Benioff short period vertical about 1948, and had one or two Wood-Anderson horizontals for many years before that. Because this station was closer to Puget Sound than any other high-sensitivity UCSS station prior to the 1980s, it is a valuable resource for comparing Puget Sound events in the magnitude 4 - 5 range.

### **Scanning Historical Seismograms**

The recent availability of low-cost scanners has made it easy to “copy” the seismograms, and a few hundred records have been scanned to date. I have been scanning photographic records at 300 dpi, and smoked paper records at 600 dpi. 300 dpi seems about right for the photographic records, but high frequency details of smoked paper records may benefit from a higher resolution scan than 600 dpi. Common imaging software can be used to correct and enlarge the slow-drum-speed, low contrast smoked paper records. Records originally recorded photographically often show a great deal of detail when scanned and enlarged. The PI believes that some really interesting new results will be possible as the result of the wedding of the new image enhancement software and the old seismograms.

A desirable step is creation of a time series from a seismogram image. While this step has not yet been taken in this portion of the study (at BSU), several commercially available image-to-coordinate software packages for the PC have been identified and one will be selected in the near future. It is doubtful that the process can be completely automated, but hopefully it can be made simple and efficient.

### **Example Seismograms**

Figure 1 shows an example of how a low contrast smoked paper original can be enlarged and enhanced. While there are inevitable limitations to the process, the figure shows a noticeable improvement. It may be reasonably argued that the same end result could be accomplished photographically. While this is probably true, the ease of using the scanner and the low expense and comparatively small amount of effort involved makes me feel that the methodology being employed in this study is something of a breakthrough.

Figure 2 shows seismograms from the earliest event that has multiple recording stations. This is the 17 July 1932 Tolt River earthquake near Seattle, magnitude around 5. The Seattle original record has been lost, but a blueline copy is in the archive and was scanned. A fairly clear polarity and S-P interval are evident on this record. The SPO records do not record a clear P onset, but the Lg phase is fairly impulsive. Comparison of these seismograms with those for events in the same area presently being recorded by UW telemetry stations in Spokane would be likely to yield a distance estimate. Records from Victoria are known to exist, so an instrumental epicenter for this event appears to be an achievable goal.

## Seismogram Scan and Enhanced Image

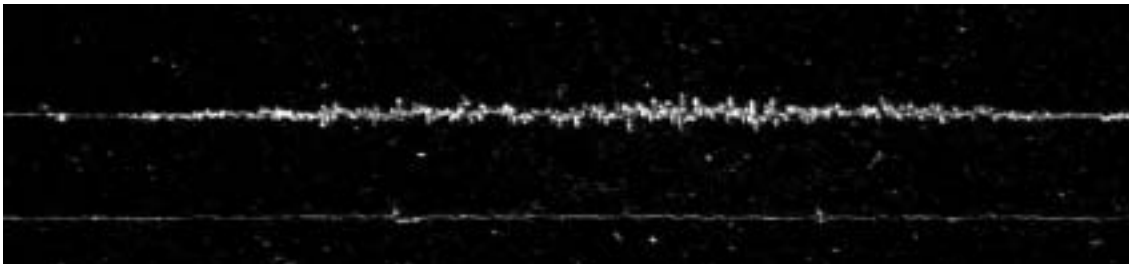
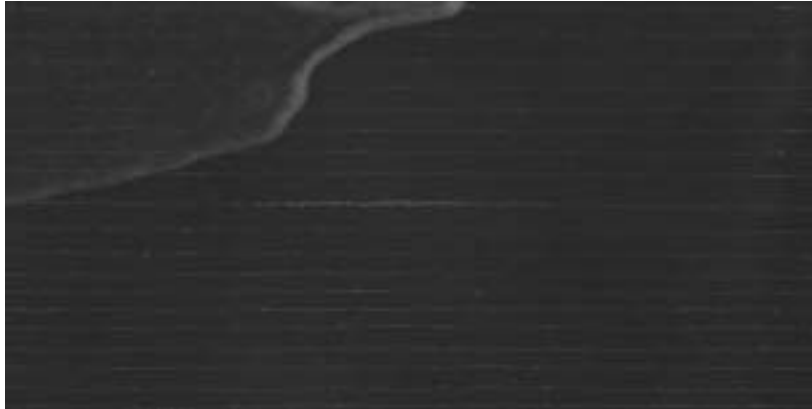


Figure 1. Original seismogram scan (portion of original record), and enhanced 4x enlargement showing detail visible. This is a very small amplitude record, but noticeable detail including some phase arrivals are visible on the enhanced enlargement. Spokane Wiechert NS record of Mt. Vernon earthquake of 26 January 1957, magnitude about 5, distance about 350 km. Original scan 600 dpi. Some of the trace “ghosting” is due to use of JPEG file compression interacting with the enhancement process, while some is the result of the stylus tip itself. This example illustrates that useful information can be extracted even from rather poor original records.

## July 17, 1932 Tolt River Earthquake

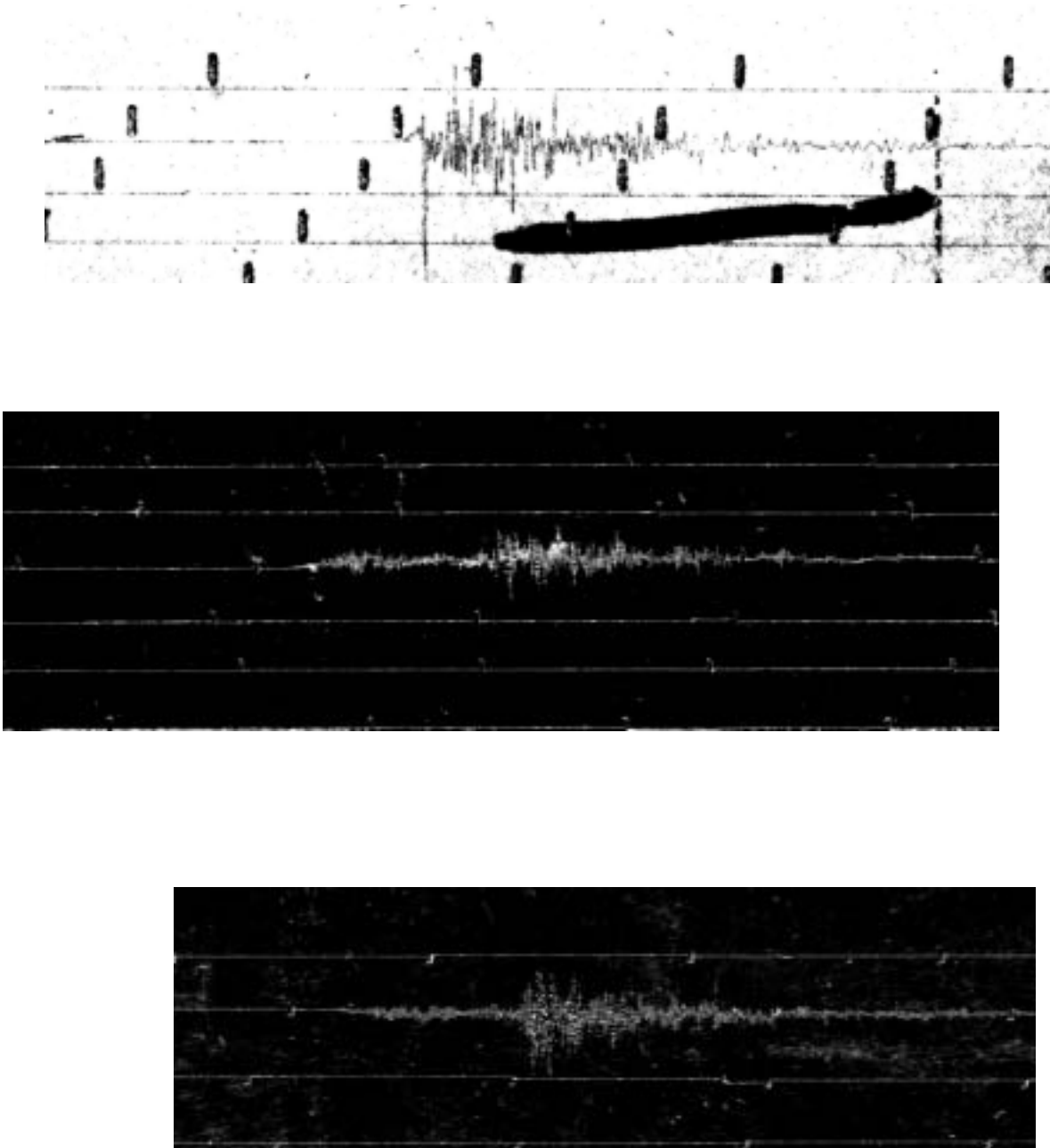


Figure 2. Enhanced scanned images of seismograms of 17 July 1932 Tolt River earthquake, magnitude  $5\frac{1}{4}$ . Top, blue-line copy of Seattle Bosch-Omori EW (originals missing at present). Middle, Spokane Wiechert WE. Bottom, Spokane Wiechert NS. Images are enlarged 3x. Time marks are at 1 minute intervals. Gains on original seismograms: Seattle Bosch-Omori 35, Spokane Wiechert 80.

Figure 3 shows the famous Milton-Freewater earthquake of 1936 (M about 6) as recorded at SEA. The remarkable feature of these records is the strong surface wave recording. The event must have been very shallow.

Figure 4 shows the earliest known instrumentally recorded Cascadia intraslab earthquake, the 1939 M $5\frac{3}{4}$  event at a depth of about 60 km. The depth has been estimated from a pP interval at teleseismic distance. The original SEA records are missing, but a copy of the EW component is in the archive. Clear P first motions are recorded at both stations. The SEA record appears to also have the S wave recorded, although some comparison with current events in the same area would be helpful to confirm this.

Figure 5 shows an M $5\frac{1}{2}$  crustal earthquake in the North Cascades east of Seattle. This is presently the largest known instrumentally recorded crustal earthquake in the North Cascades. A clear S-P interval of 8 s is observable on the SEA NS record. The SPO record exists, but was not scanned before being sent to UTEP. The P polarity is also sharp and clear. The EW record exists, but the scan was not satisfactory. A good photograph of the EW record exists, that the PI had made a number of years ago. This points out that perhaps better results can be achieved with the scanner than are presently being accomplished. I feel that scanning at a higher resolution and adjusting the contrast at the time of scanning (rather than later) may be the key to better images.

Figure 6 shows the 1946 earthquake, which was probably a crustal event although it is often listed as intraslab. The original SEA records were scanned. The original SPO records exist, but were not scanned before being sent to UTEP. There are a couple of potential choices for the S wave, but the P wave polarity is unambiguous. The detail is a little rough, probably because I should have scanned it at higher resolution. Nevertheless, the detail is certainly still digitizable.

Figure 7 shows some scanned photographic records. I was impressed that the enlargements of these records were still quite good, even at 3-5 times. Note that the detail of the top seismogram in Figure 7 is not blurred in the original image; the blurring seen on the page is due to the interaction between the resolutions of the original scan and the laser printer. This good quality of enlargement means that higher timing resolution may be achievable on clear arrivals. The originals were recorded at 30 mm/min, which implies a timing resolution of 0.2 s for sharp arrivals when the original seismogram is read with a millimeter scale to 0.1 mm. Figure 7 shows that great enlargement (the detail is equivalent to 150 mm/min) can lead to better picks. The 1957 earthquake record shows that most of the original detail could be readily digitized as far as the S phase.

Seismograms from the 1965 Seattle earthquake (M 6.5) are shown in Figure 8. These enlarged images come from two very close stations, SEA and LON. They appear to show multiple rupture events in the first second of the P wave recording. It is believed these are rupture events since these stations are so close to the epicenter that the direct ray from the hypocenter should be the first arrival, because the general pattern of inflections on the P wave is similar, and because the recordings are slightly different in detail.

## July 16, 1936 Milton-Freewater Earthquake

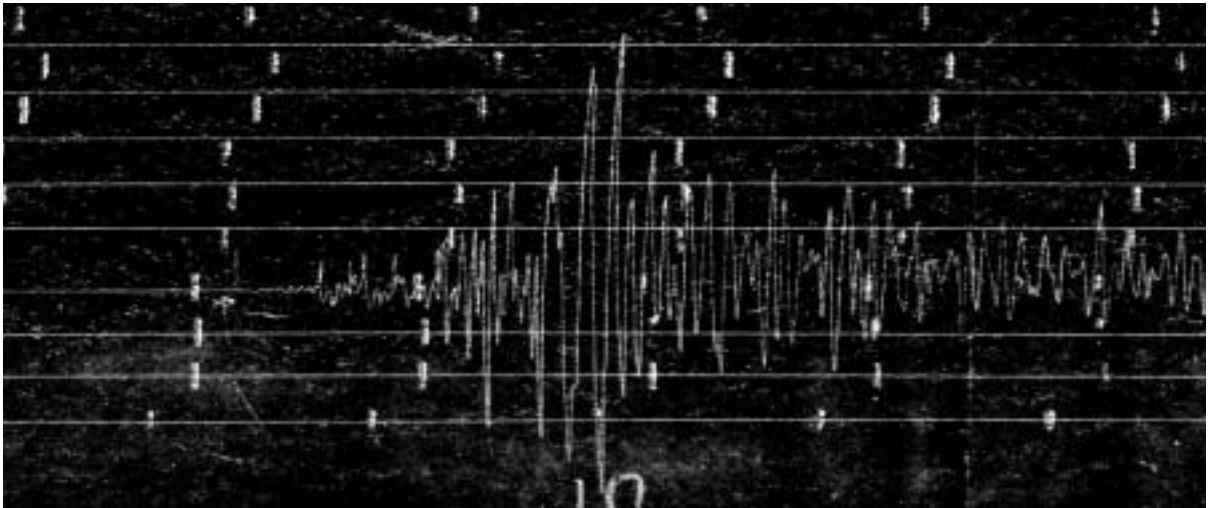
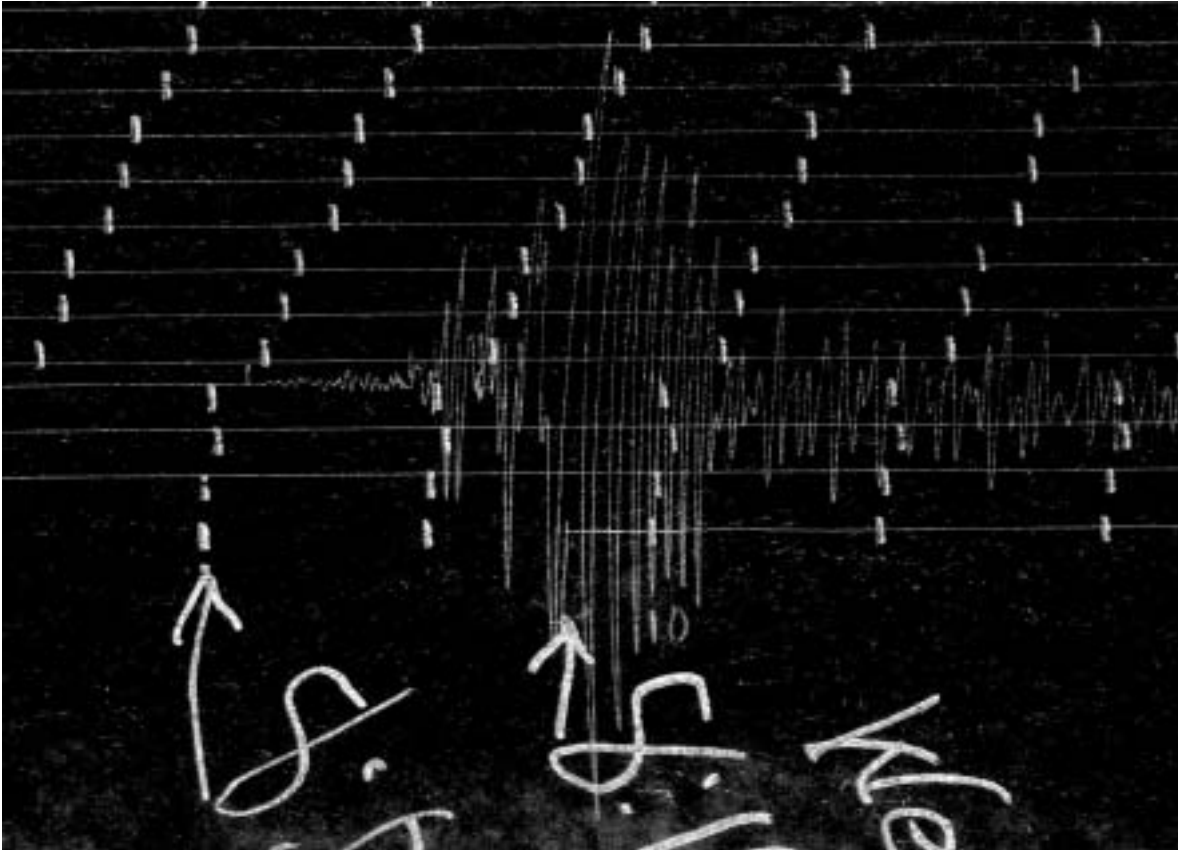


Figure 3. Enhanced scanned images of Seattle Bosch-Omori seismograms for 1936 Milton-Freewater earthquake, magnitude ~6. Top, NS component; bottom, EW. Images are 2x. Note the strong surface waves.

## November 13, 1939 Puget Sound Earthquake

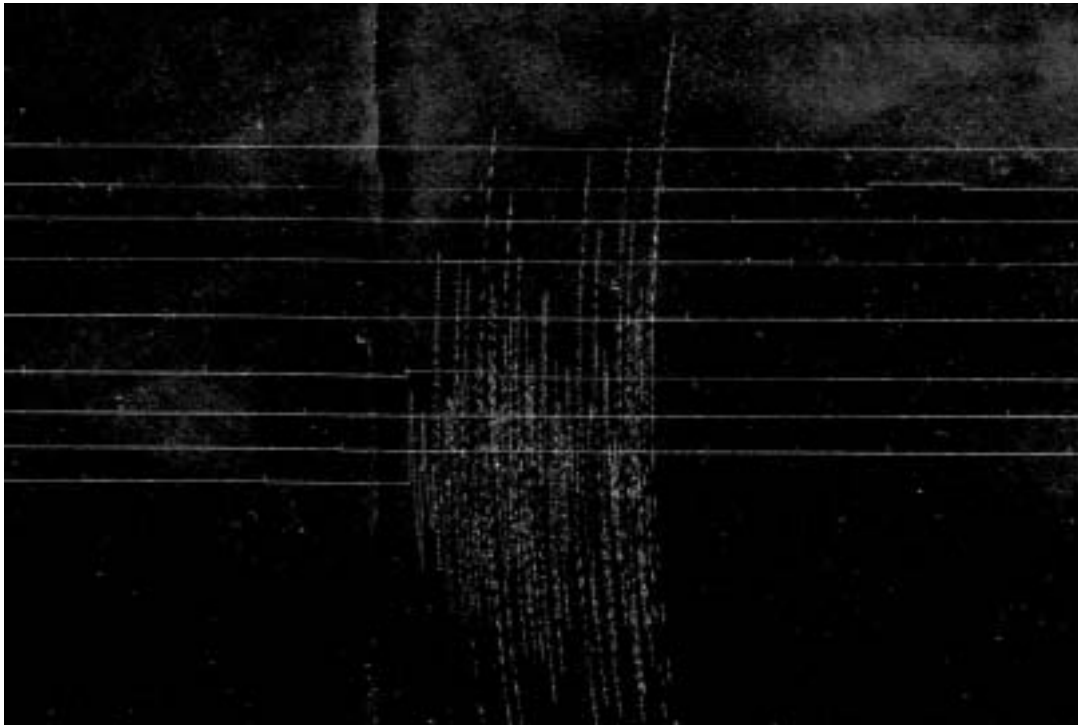
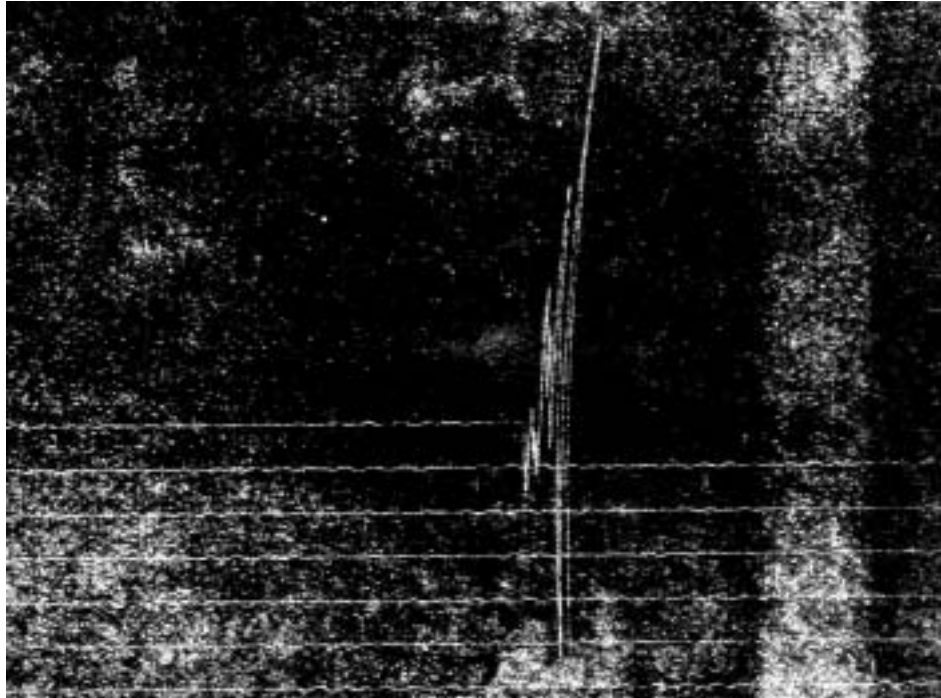


Figure 4. Enhanced scanned images of seismograms of 13 November 1939 earthquake, magnitude  $5\frac{3}{4}$ , depth 60 km. Top, Seattle Bosch-Omori EW (from copy, originals missing). Bottom, Spokane Wiechert WE. Spokane NS not shown. Images 2x.

## April 29, 1945 North Bend Earthquake

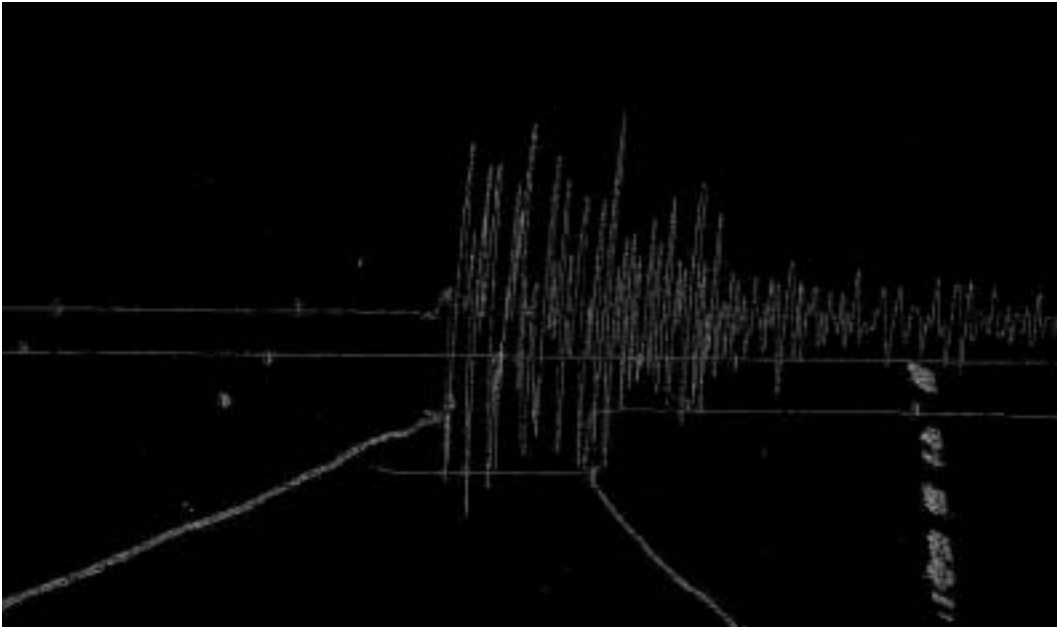


Figure 5. Enhanced scanned image of Seattle Bosch-Omori NS record of 29 April 1945 North Bend earthquake, magnitude  $5\frac{1}{2}$ . Image is 2x. EW record did not scan well and will repeated at a later date.

## February 15, 1946 Puget Sound Earthquake

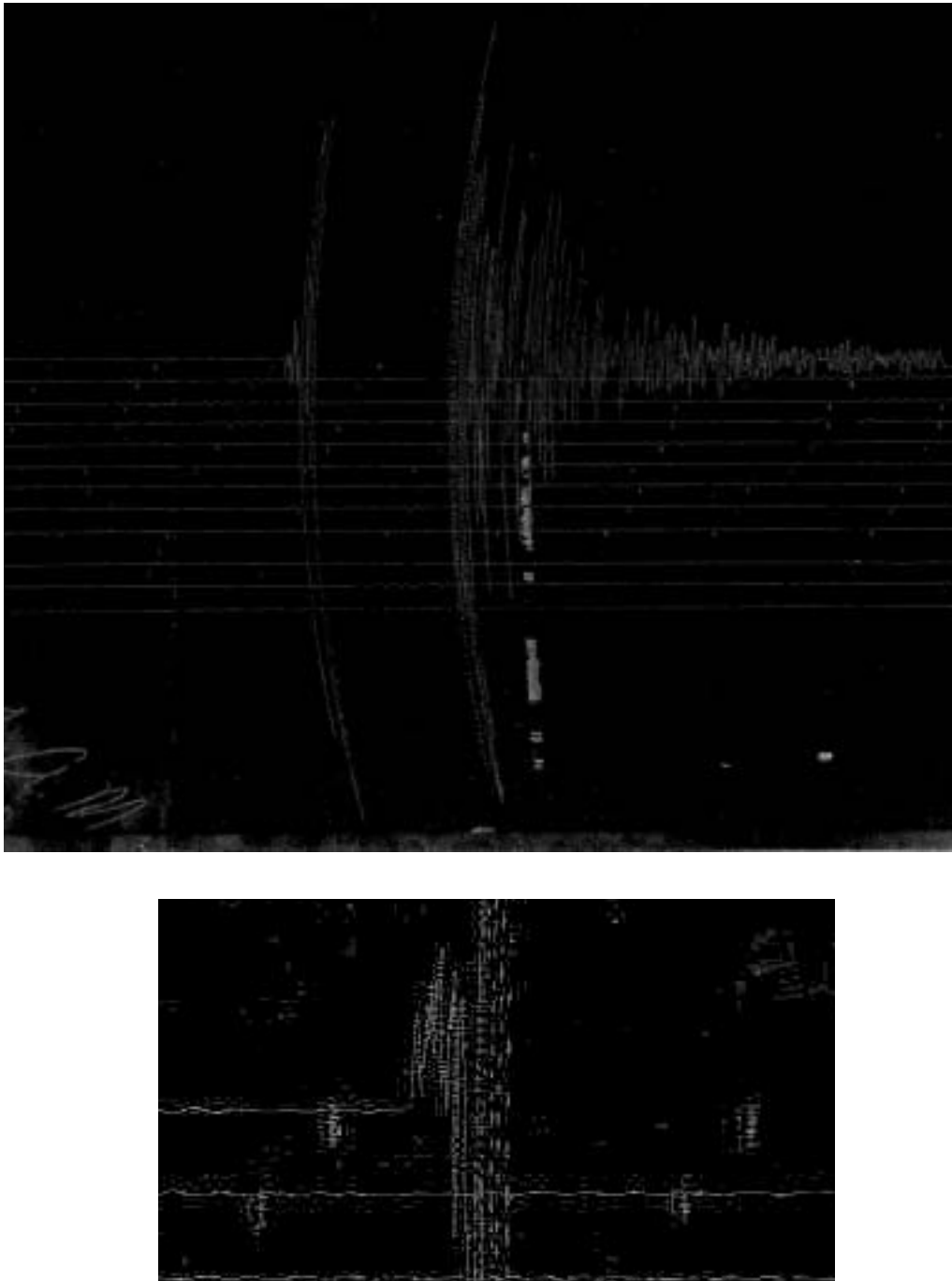
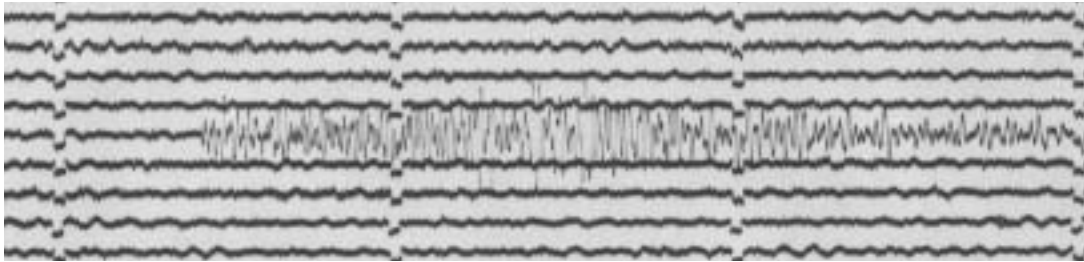


Figure 6. Enhanced scanned seismograms for Puget Sound earthquake of 15 February 1946, magnitude  $5\frac{3}{4}$ . Top, Seattle Bosch-Omori NS, actual size. Bottom, detail of Seattle Bosch-Omori EW, magnified 4x. Note the detail visible despite the high frequency content. Originals scanned at 300 dpi. Trace “ghosting” due in part to combination of coarse scanning and JPEG image compression when enhanced.

### **December 16, 1953 Portland Earthquake**



### **January 26, 1957 Mt. Vernon Earthquake**

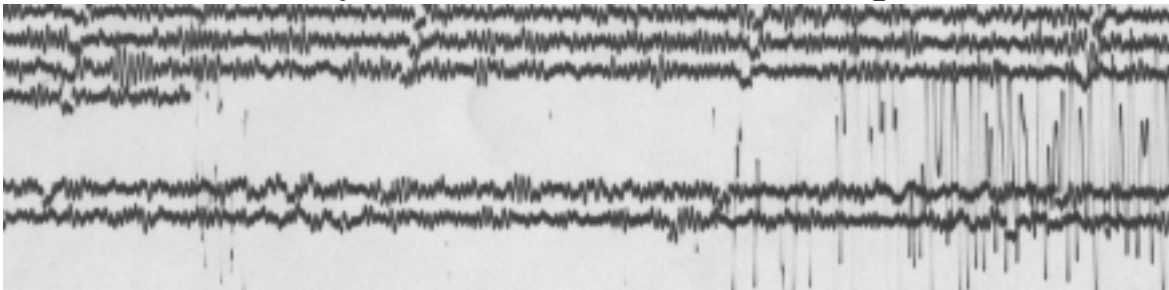


Figure 7. Seattle Sprengnether short period seismograms of earthquakes in 1953 and 1957. Both earthquakes are listed as being about magnitude 5, although the 1953 earthquake is clearly much smaller. The original seismograms are photographic. These images are enlarged 1.5x but are not otherwise enhanced. Much detail is visible at greater enlargement for seismograms that are not underexposed. The second seismogram of the Portland event is a 5x enlargement of the P wave section of the first record. “Ghosting” and blurring on the enlargement is the result of spatial aliasing between the scan and laser printer resolutions and is not seen on the actual image.

## April 29, 1965 Seattle Earthquake

### Evidence of Multiple Ruptures in First Second

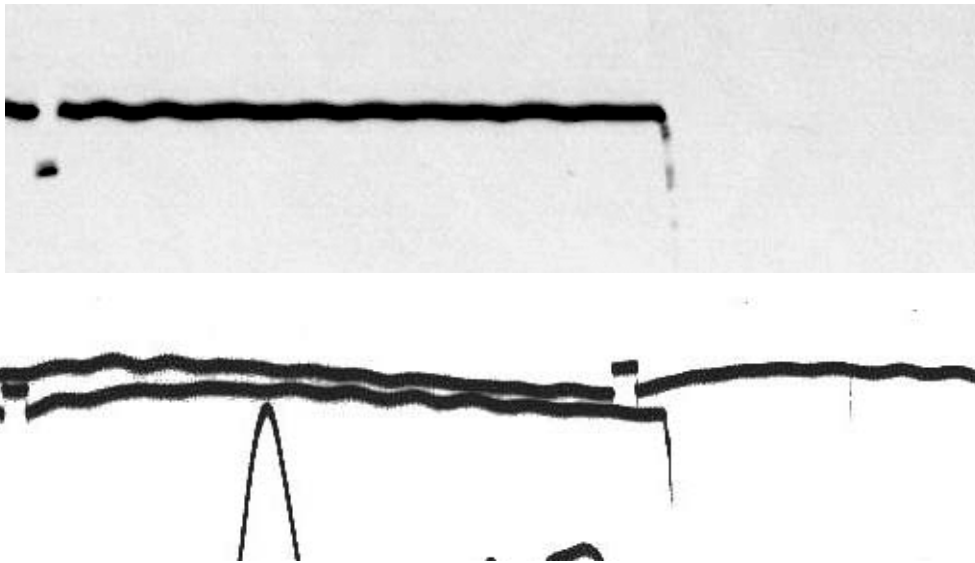


Figure 8. Seattle (top) and Longmire (bottom) long period NS images of P wave of 29 April 1965 Seattle earthquake (magnitude 6.5, depth 60 km). These images are 3.0x enlargements and have the same time scale (clock corrections differ). Time mark on Longmire record is 2.0 s in length. Both stations are within 100 km of the epicenter but are at much different azimuths. The Seattle record shows evidence of 4 rupture events within the first second, while the Longmire record shows at least three.

### **Interevent Comparisons from the Berkeley Archive**

As an example of what kinds of new information, besides source mechanisms, are likely to be gleaned from the historical seismograms, images of the P onset of several events recorded at MIN are shown in Figure 9. MIN is an excellent comparison station for these events, since it is relatively close to Puget Sound, has high sensitivity, and operated exactly the same instrument at the same gain for many years (including the time interval including all the events shown in Figure 9. The seismograms are unenhanced, although extraneous traces have largely been erased (manual erasure is a tedious job which it is hoped can be circumvented in the future).

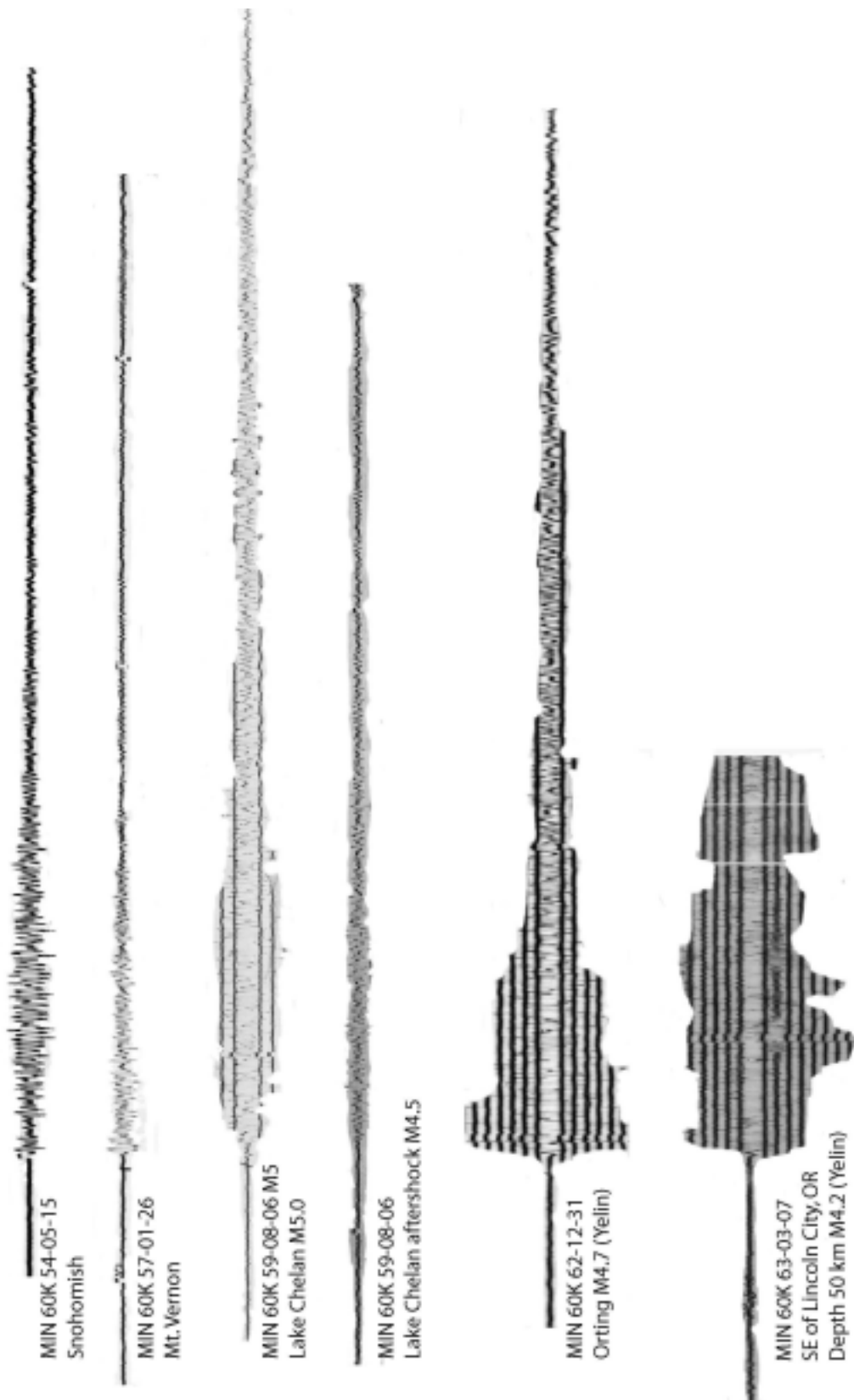
All three of the topmost seismograms are from events (probably all crustal) believed to have magnitude about 5. The seismograms show that these events are of roughly similar magnitude, probably within about 0.4 unit. Surprisingly, however, the 1962 Orting and 1963 Lincoln City earthquakes, assigned magnitudes of 4.7 and 4.2 by Tom Yelin (personal communication), recorded with much larger amplitudes than might be expected. Yelin believes the Lincoln City event to be intraslab, but the Orting event is thought to be crustal. The Lincoln City event is significantly closer to MIN than the others, but this probably doesn't completely explain the high amplitudes.

The interevent comparison suggests that either the 1962 and 1963 events have underestimated magnitude, or that the 1954, 1957, and 1959 events are overestimated. From information available to date, it is considered more likely that the 1960s events are underestimated. However, this needs to be investigated more closely.

### **Conclusions**

These preliminary results are very encouraging, both in terms of obtaining high quality image data from historical seismograms and for interpreting that data. It is now expected that epicentral information on some of the early events can be derived, something not anticipated at the beginning of this study.

Table 3 lists the approximately 375 seismograms which have been copied or scanned and can be used in this project's studies.



Mineral, California Benioff short-period vertical. Instrument had same gain for all events (60K). The vertical scale is not exact, but all relative scales are correct.

Figure 9. Interevent comparison from MIN seismograms.

**TABLE 3. SEISMOGRAMS COPIED TO DATE**

DATE	LOC*	STATION	SEISMOGRAM**		COMMENTS	
07-17-32	WWA	SEA	BO	EW	blueline copy	
07-17-32	WWA	SPO	WIE	NS&EW		
07-17-32	WWA	BRK	GW	Z		
07-17-32	WWA	BRK	GW	EW		
07-17-32	WWA	FLO	GW	Z	dead	
07-17-32	WWA	FLO	GW	NS		
07-17-32	WWA	FLO	GW	EW	2 exposures	
07-16-36	EWA	SEA	BO	NS		
07-16-36	EWA	SEA	BO	EW		
07-16-36	EWA	BRK	BEN	SPZ		
07-16-36	EWA	BRK	WA	NS		
07-16-36	EWA	BRK	WA	EW		
07-16-36	EWA	BRK	GW	Z		
07-16-36	EWA	BRK	GW	NS		
07-16-36	EWA	BRK	GW	EW		
07-16-36	EWA	BRK	WIE	Z		
07-16-36	EWA	BRK	BO	NS		
07-16-36	EWA	BRK	BO	EW		
07-16-36	EWA	FER	BO	NS		
07-16-36	EWA	FER	BO	EW		
07-16-36	EWA	USF	WA	NS		
07-16-36	EWA	FRE	WA	NS		
07-16-36	EWA	PAC	WA	NS		
07-16-36	EWA	PAC	WA	EW		
07-16-36	EWA	MHC	WA	NS		
07-16-36	EWA	MHC	WA	EW		
07-16-36	EWA	COL	W	NS	2 exposures	HSFP
07-16-36	EWA	COL	W	EW		HSFP
07-16-36	EWA	FLO	WA	NS		
07-16-36	EWA	FLO	WA	EW	2 exposures	
07-16-36	EWA	FLO	GW	Z	hopelessly light	
07-16-36	EWA	FLO	GW	NS	2 exposures	
07-16-36	EWA	FLO	GW	EW	2 exposures	
07-16-36	EWA	OTT	WIE	Z		
07-16-36	EWA	OTT	BO	NS&EW		
07-16-36	EWA	OTT	MS	NS		
07-16-36	EWA	OTT	MS	EW		
07-16-36	EWA	PAS		Misc		HSFP
07-16-36	EWA	SJP		NS?		HSFP
07-16-36	EWA	SJP		EW		HSFP
07-16-36	EWA	SLM	WA	NS	light original	
07-16-36	EWA	SLM	WA	EW	2 exposures	

07-16-36 EWA	SLM	GW?	NS	May be Mac	
07-16-36 EWA	SLM	GW?	EW	May be Mac	
07-16-36 EWA	WES	BEN	SPZ		
11-13-39 WWA	SEA	BO	NS	copy	
11-13-39 WWA	SPO	WIE	NS&EW		
11-13-39 WWA	BRK	BEN	SPZ		
11-13-39 WWA	BRK	WA	NS		
11-13-39 WWA	BRK	WA	EW		
11-13-39 WWA	BRK	BO	NS		
11-13-39 WWA	BRK	BO	EW		
11-13-39 WWA	BRK	GW	Z		
11-13-39 WWA	BRK	GW	NS		
11-13-39 WWA	BRK	GW	EW		
11-13-39 WWA	FER	BO	NS		
11-13-39 WWA	FER	BO	EW		
11-13-39 WWA	PAC	WA	NS		
11-13-39 WWA	PAC	WA	EW		
11-13-39 WWA	FRE	WA	NS		
11-13-39 WWA	MIN	WA	EW		
11-13-39 WWA	CGM	WA	NS	2 exposures	
11-13-39 WWA	CGM	WA	EW	2 exposures	
11-13-39 WWA	COL	W	NS	2 parts	HSFP
11-13-39 WWA	COL	W	EW	2 parts	HSFP
11-13-39 WWA	CSC		NS&EW	2 parts	HSFP
11-13-39 WWA	FLO	WA	NS	INOP	
11-13-39 WWA	FLO	WA	EW	2 exposures	
11-13-39 WWA	FLO	GW	Z	2 exposures	
11-13-39 WWA	FLO	GW	NS	2 exposures	
11-13-39 WWA	FLO	GW	EW		
11-13-39 WWA	LRA	WA	NS		
11-13-39 WWA	LRA	WA	EW		
11-13-39 WWA	OTT	B	SPZ		
11-13-39 WWA	OTT	MS	NS		
11-13-39 WWA	OTT	MS	EW		
11-13-39 WWA	PAS		Misc		HSFP
11-13-39 WWA	SJP		NS	No record filmed	HSFP
11-13-39 WWA	SJP		EW		HSFP
11-13-39 WWA	SLM	WA	NS		
11-13-39 WWA	SLM	WA?	EW		
11-13-39 WWA	WES	BEN	SPZ	3 copies	
11-13-39 WWA	WES	BEN	LPZ	2 copies	
11-01-42 NID	SPO	WIE	NS&EW		
11-01-42 NID	SEA	BO	NS		
11-01-42 NID	SEA	BO	EW		
11-01-42 NID	FLO	GW	Z		
11-01-42 NID	FLO	GW	NS		

11-01-42 NID	FLO	GW	EW		
07-12-44 WID	COL	W	NS	2 parts	HSFP
07-12-44 WID	COL	W	EW	2 parts	HSFP
07-12-44 WID	CSC		NS		HSFP
07-12-44 WID	CSC		EW		HSFP
07-12-44 WID	FLO	WA	NS		
07-12-44 WID	FLO	WA	EW		
07-12-44 WID	FLO	GW	Z		
07-12-44 WID	FLO	GW	NS	No record	
07-12-44 WID	FLO	GW	EW	2 exposures	
07-12-44 WID	LRA	WA	NS		
07-12-44 WID	PAS		Misc		HSFP
07-12-44 WID	SJP		NS		HSFP
07-12-44 WID	SJP		EW		HSFP
07-12-44 WID	SLM	MAC	SPZ		
07-12-44 WID	SLM	WA	NS		
07-12-44 WID	SLM	WA	EW		
07-12-44 WID	SLM	MAC	NS		
07-12-44 WID	SLM	MAC	EW		
02-14-45 WID	CSC		NS	record dated 2/14 ?	HSFP
02-14-45 WID	CSC		EW	record dated 2/14?	HSFP
02-14-45 WID	FLO	WA	NS		
02-14-45 WID	FLO	WA	EW		
02-14-45 WID	FLO	GW	Z	2 exposures	
02-14-45 WID	FLO	GW	NS		
02-14-45 WID	FLO	GW	EW		
02-14-45 WID	PAS		Misc		HSFP
02-14-45 WID	SJP		NS	No signal above noise	
02-14-45 WID	SJP		EW	record dated 2/14?	HSFP
02-14-45 WID	SLM	MAC	NS		
02-14-45 WID	SLM	MAC	EW		
04-29-45 WWA	SEA	BO	NS		
04-29-45 WWA	SEA	BO	EW		
04-29-45 WWA	BRK	BEN	SPZ		
04-29-45 WWA	BRK	WA	NS		
04-29-45 WWA	BRK	WA	EW		
04-29-45 WWA	BRK	GW	Z		
04-29-45 WWA	BRK	GW	NS		
04-29-45 WWA	BRK	GW	EW		
04-29-45 WWA	MIN	WA	EW		
04-29-45 WWA	MHC	WA	EW		
04-29-45 WWA	MHC	WA	NS		
04-29-45 WWA	FRE	WA	NS		
04-29-45 WWA	COL	W	NS		HSFP
04-29-45 WWA	COL	W	EW		HSFP
04-29-45 WWA	FLO	WA	NS	2 exposures	

04-29-45 WWA	FLO	WA	EW		
04-29-45 WWA	FLO	GW	Z		
04-29-45 WWA	FLO	GW	NS		
04-29-45 WWA	FLO	GW	EW		
04-29-45 WWA	OTT	BEN	SPZ		
04-29-45 WWA	OTT	MS	NS		
04-29-45 WWA	OTT	MS	EW		
04-29-45 WWA	PAS		Misc		HSFP
04-29-45 WWA	SJP		NS	2 parts	HSFP
04-29-45 WWA	SJP		EW	2 parts	HSFP
04-29-45 WWA	SLM	MAC	SPZ	2 exposures	
04-29-45 WWA	SLM	WA	NS		
04-29-45 WWA	SLM	WA	EW	2 exposures	
04-29-45 WWA	SLM	MAC	NS		
04-29-45 WWA	SLM	MAC	EW		
04-29-45 WWA	SPO	WIE	NS		
04-29-45 WWA	SPO	WIE	NS		
04-29-45 WWA	WES	BEN	SPZ		
04-29-45 WWA	WES	BEN	LPZ		
02-15-46 WWA	SEA	BO	NS		
02-15-46 WWA	SEA	BO	EW		
02-15-46 WWA	BRK	BEN	SPZ		
02-15-46 WWA	BRK	WA	NS		
02-15-46 WWA	BRK	WA	EW		
02-15-46 WWA	BRK	GW	Z		
02-15-46 WWA	BRK	GW	NS		
02-15-46 WWA	BRK	GW	EW		
02-15-46 WWA	BRK	WIE	Z		
02-15-46 WWA	BRK	BO	EW		
02-15-46 WWA	MIN	WA	EW		
02-15-46 WWA	USF	WA	EW		
02-15-46 WWA	USF	WA	NS		
02-15-46 WWA	PAC	WA	NS		
02-15-46 WWA	PAC	WA	EW		
02-15-46 WWA	FRE	WA	NS		
02-15-46 WWA	COL	W	NS		HSFP
02-15-46 WWA	COL	W	EW		HSFP
02-15-46 WWA	CSC		NS		HSFP
02-15-46 WWA	CSC		EW		HSFP
02-15-46 WWA	FLO	WA	NS		
02-15-46 WWA	FLO	WA	EW	2 exposures	
02-15-46 WWA	FLO	GW	Z		
02-15-46 WWA	FLO	GW	NS		
02-15-46 WWA	FLO	GW	EW		
02-15-46 WWA	OTT	MS	NS		
02-15-46 WWA	OTT	MS	EW		

02-15-46 WWA	PAS		Misc		HSFP
02-15-46 WWA	SJP		NS		HSFP
02-15-46 WWA	SJP		EW		HSFP
02-15-46 WWA	SLM	MAC	SPZ		
02-15-46 WWA	SLM	WA	NS		
02-15-46 WWA	SLM	WA	EW		
02-15-46 WWA	SLM	MAC	NS		
02-15-46 WWA	SLM	MAC	EW		
02-15-46 WWA	SPO	WIE	NS		
02-15-46 WWA	SPO	WIE	EW		
02-15-46 WWA	WES	BEN	SPZ	2 copies	
02-15-46 WWA	WES	BEN	LPZ		
04-13-49 WWA	SPO	WIE	NS		
04-13-49 WWA	SPO	WIE	EW		
04-13-49 WWA	FER	BO	NS		
04-13-49 WWA	FER	BO	EW		
04-13-49 WWA	BRK	BEN	SPZ		
04-13-49 WWA	BRK	WA	NS		
04-13-49 WWA	BRK	GW	NS		
04-13-49 WWA	BRK	GW	EW		
04-13-49 WWA	BRK	WIE	Z		
04-13-49 WWA	BRK	BO	NS		
04-13-49 WWA	BRK	BO	EW		
04-13-49 WWA	MIN	BEN	SPZ		
04-13-49 WWA	MIN	WA	NS		
04-13-49 WWA	MIN	WA	EW		
04-13-49 WWA	PAC		SPZ		
04-13-49 WWA	PAC	WA	NS		
04-13-49 WWA	PAC	WA	EW		
04-13-49 WWA	ARC	SPG	SPZ		
04-13-49 WWA	ARC	SPG	SPN		
04-13-49 WWA	ARC	SPG	SPE		
04-13-49 WWA	USF	WA	NS		
04-13-49 WWA	USF	WA	EW		
04-13-49 WWA	MHC	BEN	SPZ		
04-13-49 WWA	MHC	WA	NS		
04-13-49 WWA	REN		SPZ		
04-13-49 WWA	FRE	SPG	SPZ		
04-13-49 WWA	FRE	SPG	SPN		
04-13-49 WWA	MHC	WA	EW		
04-13-49 WWA	COL	W	NS	2 exposures	
04-13-49 WWA	DBN		LPZ		
04-13-49 WWA	DBN		LPN		
04-13-49 WWA	DBN		LPE		
04-13-49 WWA	FLO	WA	NS	poor original	
04-13-49 WWA	FLO	WA	EW	poor original	

04-13-49 WWA	FLO	GW	Z	2 exposures	
04-13-49 WWA	FLO	GW	NS	no record	
04-13-49 WWA	FLO	GW	EW	hopelessly light	
04-13-49 WWA	PAS		Misc		HSFP
04-13-49 WWA	SJP		NS	5 parts	
04-13-49 WWA	SJP		EW	5 parts	
04-13-49 WWA	SLM	MAC	SPZ	2 exposures	
04-13-49 WWA	SLM	WA	NS		
04-13-49 WWA	SLM	WA	EW		
04-13-49 WWA	SLM	MAC	NS		
04-13-49 WWA	SLM	MAC	EW	underexposed orig	
12-16-53 WOR	SEA	MAC	SPZ		
12-16-53 WOR	SEA	SPG	SPN		
12-16-53 WOR	SEA	SPG	SPE		
12-16-53 WOR	COR	SL	SPZ		
12-16-53 WOR	COR	SL	SPN		
12-16-53 WOR	COR	SL	SPE		
12-16-53 WOR	MIN	BEN	SPZ		
12-16-53 WOR	MIN	WA	NS		
12-16-53 WOR	MIN	WA	EW		
05-15-54 WWA	SEA	MAC	SPZ		
05-15-54 WWA	SEA	SPG	SPN		
05-15-54 WWA	SEA	SPG	SPE		
05-15-54 WWA	COR	SL	SPZ		
05-15-54 WWA	COR	SL	SPN		
05-15-54 WWA	COR	SL	SPE		
05-15-54 WWA	MIN	BEN	SPZ		
05-15-54 WWA	MIN	WA	NS		
05-15-54 WWA	MIN	WA	EW		
05-15-54 WWA	BRK	BEN	SPZ		
05-15-54 WWA	PAC		SPZ		
05-15-54 WWA	MHC	BEN	SPZ		
01-26-57 WWA	SEA	MAC	SPZ		
01-26-57 WWA	SEA	SPG	SPE	NS missing (cut out)	
01-26-57 WWA	SPO	WIE	NS&EW		
01-26-57 WWA	MIN	BEN	SPZ		
01-26-57 WWA	MIN	WA	NS		
01-26-57 WWA	MIN	WA	EW		
01-26-57 WWA	BRK	BEN	SPZ		
01-26-57 WWA	PAC		SPZ		
01-26-57 WWA	MHC	BEN	SPZ		
08-06-59 EWA	TUM		SPZ		
08-06-59 EWA	TUM		SPN&E		
08-06-59 EWA	BRK	BEN	SPZ		
08-06-59 EWA	BRK	GW	Z		
08-06-59 EWA	BRK	GW	NS		

08-06-59 EWA	BRK	GW	EW	
08-06-59 EWA	BRK	SPG	LPZ	
08-06-59 EWA	BRK	SPG	LPN	
08-06-59 EWA	BRK	SPG	LPE	
08-06-59 EWA	COR	WL	SPZ	
08-06-59 EWA	COR	SL	SPZ	also aftershock
08-06-59 EWA	COR	SL	SPN	also aftershock
08-06-59 EWA	COR	SL	SPE	also aftershock
08-06-59 EWA	MIN	BEN	SPZ	also aftershock
08-06-59 EWA	MIN	WA	NS	also aftershock
08-06-59 EWA	MIN	WA	EW	also aftershock
08-06-59 EWA	PAC		SPZ	
08-06-59 EWA	MHC	BEN	SPZ	also aftershock
08-06-59 EWA	MHC	WA	NS	
08-06-59 EWA	MHC	WA	EW	
08-06-59 EWA	FLO	GW	Z	
08-06-59 EWA	FLO	GW	NS	
08-06-59 EWA	FLO	GW	EW	
09-17-61 WWA	LON		SPZ	
09-17-61 WWA	LON		SPN	
09-17-61 WWA	LON		SPE	
09-17-61 WWA	SEA	MAC	SPZ	
09-17-61 WWA	SEA		SPN&E	
09-17-61 WWA	SEA	SPG	LPN&E	
09-17-61 WWA	SPO		NS	
09-17-61 WWA	SPO		EW	
11-07-61 WOR	COR	WL	Z	
11-06-62 WOR	COR	BEN	SPZ	from xerox
11-06-62 WOR	COR	BEN	SPN	from xerox
11-06-62 WOR	COR	BEN	SPE	from xerox
11-06-62 WOR	COR	SPG	LPZ	from xerox
11-06-62 WOR	COR	SPG	LPN	from xerox
11-06-62 WOR	COR	SPG	LPE	from xerox
11-06-62 WOR	TUM		SPZ	
11-06-62 WOR	TUM		SPN	
11-06-62 WOR	TUM		SPE	
11-06-62 WOR	SEA	MAC	SPZ	
11-06-62 WOR	SEA		SPN&E	
11-06-62 WOR	SEA		LPN&E	
11-06-62 WOR	SPO		NS	
11-06-62 WOR	SPO		EW	
11-06-62 WOR	FLO	GW	Z	
11-06-62 WOR	FLO	GW	NS	
11-06-62 WOR	FLO	GW	EW	
12-31-62 WWA	SEA	MAC	SPZ	
12-31-62 WWA	SEA		SPN	

12-31-62 WWA	SEA		SPE	
12-31-62 WWA	SEA	SPG	LPN	
12-31-62 WWA	SEA	SPG	LPE	
12-31-62 WWA	TUM		SPZ	
12-31-62 WWA	TUM		SPN&E	
12-31-62 WWA	SPO		NS	
12-31-62 WWA	SPO		EW	
12-31-62 WWA	COR	SPG	LPZ	from xerox
12-31-62 WWA	COR	SPG	LPN	from xerox
12-31-62 WWA	COR	SPG	LPE	from xerox
12-31-62 WWA	MIN	BEN	SPZ	
12-31-62 WWA	MIN	WA	NS	
12-31-62 WWA	MIN	WA	EW	
12-31-62 WWA	FLO	GW	Z	
12-31-62 WWA	FLO	GW	NS	
12-31-62 WWA	FLO	GW	EW	
03-07-63 WOR	MIN	BEN	SPZ	
07-14-64 WWA	SEA	MAC	SPZ	
07-14-64 WWA	SEA	WA	NS&EW	
07-14-64 WWA	SEA	SPG	LPN&E	
07-14-64 WWA	TUM		SPZ	
07-14-64 WWA	TUM		SPN	
07-14-64 WWA	TUM		SPE	
07-14-64 WWA	LON	BEN	SPZ	
07-14-64 WWA	LON	BEN	SPN	
07-14-64 WWA	LON	BEN	SPE	
07-14-64 WWA	LON	SPG	LPZ	
07-14-64 WWA	LON	SPG	LPN	
07-14-64 WWA	LON	SPG	LPE	
07-14-64 WWA	FLO	GW	Z	
07-14-64 WWA	FLO	GW	NS	
07-14-64 WWA	FLO	GW	EW	
04-29-65 WWA	SEA	MAC	SPZ	
04-29-65 WWA	SEA		SPN&E	
04-29-65 WWA	SEA	WA	NS	
04-29-65 WWA	SEA	WA	EW	
04-29-65 WWA	SEA	SPG	LPN&E	
04-29-65 WWA	TUM		SPZ	
04-29-65 WWA	TUM		SPN	
04-29-65 WWA	TUM		SPE	
04-29-65 WWA	LON	BEN	SPZ	
04-29-65 WWA	LON	BEN	SPN	
04-29-65 WWA	LON	BEN	SPE	
04-29-65 WWA	LON	SPG	LPZ	
04-29-65 WWA	LON	SPG	LPN	
04-29-65 WWA	LON	SPG	LPE	

04-29-65 WWA	FLO	GW	Z	
04-29-65 WWA	FLO	GW	NS	
04-29-65 WWA	FLO	GW	EW	
04-29-65 WWA	OTT	WM	SPZ	
04-29-65 WWA	OTT	WM	SPN	
04-29-65 WWA	OTT	SPG	LPZ	
04-29-65 WWA	OTT	SPG	LPN	
04-29-65 WWA	OTT	SPG	LPE	
04-29-65 WWA	WES	BEN	SPZ	
04-29-65 WWA	WES	BEN	LPZ	
04-29-65 WWA	DBN		LPZ	
04-29-65 WWA	DBN		LPN	
04-29-65 WWA	DBN		LPE	
06-03-68 SOR	LON	BEN	SPZ	also related events
06-03-68 SOR	LON	BEN	SPN	
06-03-68 SOR	LON	BEN	SPE	
06-03-68 SOR	LON	SPG	LPZ	
06-03-68 SOR	LON	SPG	LPN	
06-03-68 SOR	LON	SPG	LPE	

\*Locations: WWA – western Washington, WOR – western Oregon, EWA – eastern Washington, SOR – southern Oregon, NID – northern Idaho, WID – western Idaho.

\*\*Types of seismograph: BO – Bosch-Omori, WIE – Wiechert, GW – Galitzin-Wilip, W – Wenner, WA – Wood-Anderson, MS – Milne-Shaw, B or BEN – Benioff, MAC – Macelwane-Sprengnether, SL – Slichter, SPG – Sprengnether, WL – Wilson Lamison, WM – Willmore

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